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INDEX TO BENET LABORATORIES TECHNICAL REPORTS - 1998

R. D. NEIFELD

APRIL 1999



US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

CLOSE COMBAT ARMAMENTS CENTER BENÉT LABORATORIES WATERVLIET, N.Y. 12189-4050



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oncentration as a function of a radial str considered. The standard analysis is for ad facilitates the calculation of a family of gree British buttress, a 15-degree asyn	ess in the joint. An addition a single-thread tooth, isolat f characteristic curves. Thi ametric "V," the 20-degree	nal set of characteristic c ed from a long chain of i s work presents the char Benet buttress, and a sp	racteristic Curve," which defines the basic streatures is produced when the general stress field identical teeth, that is computationally efficient acteristic plots for four different threads, the acteristic plots for four different threads were possibility of a standard thread family for high
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13. ABSTRACT (Maximum 200 words)

Dicyandiamide—a solid with a melting point of 209°C—is one of a unique group of curing agents that are insoluble in epoxy at room temperature. As a curing agent for epoxy resins, dicyandiamide can react through all four nitrogen groups—reacting with the resin at both epoxide and hydroxyl sites. When mixed with either diglycidyl ether of bisphenol A or diglycidyl ether of tetrabromobisphenol A, the formulation is stable enough to be stored for 6 to 12 months. Because dicyandiamide's solubility is low at room temperature, the curing reaction is limited until the temperature increases enough to dissolve the curing agent. To improve the ability to process the resin, an accelerator (such as diuron) can be added to reduce the curing temperature. The curing reaction then proceeds via a complex mechanism that is not dominated by a single reaction. Each compound's effect on the cured material was studied by measuring changes in the glass transition temperature.

14. SUBJECT TERMS

Curing Agents, Accelerator, Glass Transition, Epoxy, Resins, Diglycidyl Ether of Bisphenol A

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GaAs(100). The alloy films were grown the heteroepitaxial orientation of the C mismatch, occurred for depositions perfo temperature or reducing the Ge ⁺ ion	using the partially ionized bea loGe ₂ deposits. The CoGe ₂ [rmed at a substrate temperatu energy leads to CoGe ₂ (100) ostrate temperature alone prod	im deposition technique, in 001](100) GaAs[100](001 re around 280°C and with orientation domination v	tionships of the cobalt germanide CoGe ₂ to which low energy Ge ⁺ ions are used to alter orientation, which has the smallest lattice ~1200 eV Ge ⁺ ions. Lowering the substrate with CoGe ₂ [100](010) GaAs[100](001) and orientation. For CoGe ₂ (001) films, additional
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GRAIN ORIENTATIONS IN ELECTRO UND LOW CONTRACTION CHROM	OLYTIC HIGH CONTRAC IUM DEPOSITION	TION	AMCMS No. 6111.01.91A1.1
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L. Lee, D. Windover, and K.E. Mello	(RPI, Troy, NY)		
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Several electrochemical deposition parameters affect grain orientations, which, in turn, affect coating quality and performance. An enhanced x-ray pole figure technique has been used to study grain distribution anisotropy in electrolytic high contraction (HC) and low contraction (LC) chromium. Temperature and current density are the most important factors controlling grain orientation. Production HC chromium deposited on steel at low temperature and low current density exhibited strong <111> fiber texture, while LC chromium deposited on steel at high temperature and high current density exhibited near random crystalline orientation. The drastic change in grain orientation on steel from strongly textured HC chromium to randomly oriented LC chromium is accompanied by marked differences in crack density, hardness, deposition rate, microstructure, thermal behavior upon heating and cooling, and improved wear and erosion performance. Laboratory LC chromium specimens that were deposited on copper plates with and without sample rotation and pulse current plating showed preferred (211) and (222) orientations. Although substrate material affects grain orientation, sample rotation and pulse current plating play a less important role.

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Investigation of environmental cracking o	of a 1100 MPa vield strength A7	23 steel connon tube au	biomed as a second seco
interarrographic results show clacking of th	ne steel beneath a 0.12 mm prote	ctive layer of chromium	Cracks undermine and remove costions
or curoumann and read to localized elosion fi	nat ruins the cannon. Key feature	s of the firing thermal day	mage and cracking are: [i] recrustolization
or the chromatin to a depth of up to 0.08 mr	m; [11] steel transformation to (), 19	mm below the chrome s	surface: [iii] two different periodic arrays
of cracks normal to the hoop and axial dire	ections, with mean depths of 0.23	3 and 0.46 mm, respective	ely.
Time-temperature-depth profiles for the fi	iring cycle were derived via hi-	material finite difference	a analysis of a semi infinite called autich
pheorporated carmon compusition gas tempe	ratures and material properties th	at vary as a function of	temperature. The temperature and doub
associated with the steel transformation w	ere used to solve iteratively for	the convective heat tran	isfer coefficient. This value was further
commined by the depths of chromium recrys	stalization and of the crack arrays	in the two orientations	A profile of maximum temperature versus
depth is used to determine the near-bore	applied and residual stress distr	butions within the tube	The measured volume change of steel
transformation is used to determine an upper factors for the observed crack arrays and he	ence provide some explanation for	or the differential deaths	ased to determine crack-tip stress intensity
The near-bore temperature and residual stres	ss distributions are used to help de	etermine the cause of hyd	drogen cracking and measures to prevent
cracking. Compressive yielding due to the	ermal loading produces peer her		
Prevention of cracking is discussed in 1-4	tionship to hydrogen crack growt	e tensile residual stresse	s and thereby causes hydrogen cracking.

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X-ray diffraction residual stress distribution	on analysis was performed for	a swage autofrettaged this	k walled	A723 steel compound cylinder
with axial semi-circular mid-wall channels				
of spatial resolution and the x-ray beam spre				
Tresca's model of a partially autofrettaged s				
Our experimental results verified most feat		_	_	-
stresses near the channel root areas. Howe				
channel roots. An overestimate of fatigue li				
into account. In solid autofrettaged cylind				
However, there is no analytical model in				
introduction of the semi-circular channels in				
and the channel roots are critical sites for				
sites where cracks and failure should occur	r. Fatigue test results verified	that cracking and failure o	ccurred at	the channel roots.
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undetectable spectral signature. Pure fl heights, starting at random times. However when imposing practical constraints. We pulse durations and magnitudes. We e	derived from chaos theory, have be licker pulsing requires that the cover, a significant reduction in con- thave been able to significantly comployed flicker pulsing, with a	een employed to efficiently omponents be driven with a spicuous power spectral de reduce the dominant comports. PSD approaching (1/f) ² to	ersely contribute to the spectral signature pulse circuitry while generating a virtually a set of uncorrelated pulses, with random nisity (PSD) components can be achieved onests of the power spectrum using fixed ordrive our components more efficiently, are of the equipment appears only in the
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STABILITY OF ARRAYS OF MULTIP	LE-EDGE CRACKS	Contract No. 8471-AN-06 (70-18)
6. AUTHOR(S)		
Anthony P. Parker		
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The creation and subsequent shedding of arrays of edge cracks is a natural phenomenon which occurs in heat-checked gun tubes, rapidly cooled pressure vessels, and rock, dried-out mud flats, paint, and concrete and in ceramic coatings and permafrost. The phenomenon covers five orders of magnitude in crack spacing. A simple model is developed which indicates that the shedding behaviour is governed by energy release from individual cracks rather than global energy changes. The model predicts that all cracks will deepen until a crack-spacing/crack-depth ratio (2h/a) of 3.0 is achieved, at which stage crack-shedding will commence. Two out of every three cracks will be shed, leading to a new (higher) crack-spacing/crack-depth ratio at which stage growth of all currently active cracks will be dominant.

An approach based upon rapid, approximate methods for determining stress intensity provides good indications of behaviour provided near-surface stress gradients are not excessive. In cases where stress gradients are high, it is shown that it is necessary to employ numerical techniques in calculating stress intensity. Two specific examples are presented, the first at very small scale (heat-check cracking, typical crack spacing 1mm) and the second very large scale (permafrost cracking, typical crack spacing 20m). The predicted ratios for the proportion of cracks shed and for crack-spacing/crack-depth are in agreement with experimental evidence for gun tubes, concrete, and permafrost. The ratios also appear to match experimental observations of 'island delamination' in ceramic coatings and paint films.

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6. AUTHOR(S) Anthony P. Parker (Royal Military Colleg Cranfield University, Swindon, UK) and J			
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Autofrettage is used to introduce advantageous residual stresses into pressure vessels and to enhance their fatigue lifetimes. For many years workers have acknowledged the probable influence of the Bauschinger effect which serves to reduce the yield strength in compression as a result of prior tensile plastic overload. This in turn can produce lower compressive residual hoop stresses near the bore than are predicted by 'ideal' solutions (elastic/perfectly plastic without Bauschinger effect).

There have been several models proposed in order to predict the reduced stresses within the autofrettaged tube. The purpose of this paper is simply to compare a limited set of models, including the ASME code, with available experimental evidence. Three models are compared: Model A, based upon a quasi strain-hardening model developed by Chen; Model B, based upon a Bauschinger effect which varies with plastic strain and hence with radius; Model C, which is based upon section KD-522.2 of the recently revised ASME pressure vessel code. The models are compared against experimental data under three headings:

- Measurements of Hoop Residual Stress at the Bore
- Measurements of Hoop Residual Stress Variation Radially Through the Tube Wall, In Particular the Near-Bore Region
- Measurements of Opening Angle When Autofrettaged Tubes are Slit Radially, Hence Releasing the Pure Bending Moment 'Locked In' by the Hoop Stress

14. SUBJECT TERMS Pressure Vessels, Autofrettage, Hig Bauschinger Effect	15. NUMBER OF PAGES 10 15. PRICE CODE		
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Residual stresses are believed to be response	onsible for the intrinsic cracks o	bserved in electrolytic chro	mium coatings. The cracks directly affect
the wear and erosion behavior of the c	oating and substrate. Crystalling	ne orientation significantly	influences the elastic-plastic properties of
and residual stress analysis for two low of	vnich residual stress can be deter contraction (LC) chromium coat	mined using x-ray diffractions and compare	on. For this study, we investigated texture ed the results with a high contraction (HC)
chromium specimen. High-resolution po	ole figure analysis and x-ray diffr	action were used to characte	erize the texture in the coatings. Randomly
oriented materials allow the application	of the x-ray diffraction $\sin^2 \Psi$ s	tress measurement method	For highly textured body-centered-cubic
specimens exhibited near random orien	tation with very weak fiber text	od was used to determine in ure, and the other specimen	residual stress. One of the LC chromium a exhibited intermediate mixed <111> and
<211> fiber texture. The HC chromium	specimen exhibited strong pred	ominately <111> fiber text	ure. A correlation between residual stress
and texture was found. The HC chrom	ium specimen with high fiber te	exture showed higher surface	te tensile stresses, while the LC chromium
specimens with more randomly oriented	crystaintes snowed lower resid	iual stresses.	
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Laboratory. Our phase determina dispersive x-ray analysis, and hardn used to determine residual stresses. firing, debonded coating showed	prototype triode-sputtered 23 steel cylinder. The coat ion was based on x-ray dess and electrical resistivit A locally developed high-ralpha-tantalum, preferred dother impurities. The su	ting was depos liffraction anal ly measurement esolution pole	ited for wear and erosion lysis, wavelength disper- its. Both x-ray diffraction figure technique was use tion, high surface stress	sited with a 2.5 µm niobium under-layer protection by Pacific Northwest National sive x-ray fluorescence analysis, energy in and radius-of-curvature methods were d to perform texture analysis. The postes, tantalum oxides, entrapped krypton led broadened poles and body-centered-
14. SUBJECT TERMS			•	I 45 MUNIOS OF BASE
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This paper demonstrates the application of dynamics. The approach enables design Numerical validation of the results using	problems for the structural:	response of beams subject to	ial differential equations that govern beam o shock and vibration loading to be posed. also shown.
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6. AUTHOR(S)			
Kevin Miner, Adolf Kapusta, and K	Cenneth Olsen		
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·	•	on 94 mm M3 Coal Custon	f, shoulder-fired, recoilless rifle—the
TACOM-ARDEC Multi-Role, Anti- composite-wrapped, steel-lined bard Gunner uninjured. The rifle (serial n inspection, dimensional checks, a rand Although there is no clear evidence soil obstruction in the barrel. This of	Armor, Anti-Personnel Weapon System of burst open beneath the trigger how umber 14051) was evaluated in the fragnetic particle inspection, an ultragarding the cause of the failure, the obstruction probably produced a largary the jacket that contains the presented.	em (MAAWS)—failed while fasting—destroying the weapon field and at Benet Laboratories asonic inspection, a crack evelone evidence does indicate that the feet amount of highly localized	firing an FFV552 training round. The but leaving the Gunner and Assistant is. Inspections included a bore surface raluation, and a bore debris analysis, the failure may have been caused by a stress on the carbon fiber, composite-ressurized propellant gases to deform
14. SUBJECT TERMS Gun Failure, Carl Gustaf, MAAWS, Ultrasonic Inspection, Magnetic Par	M3, Composites, Composite Gun B ticle Inspection, Scanning Electron I	arrels, Microscopy	15. NUMBER OF PAGES 31
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USE OF THE INSTRUMENTED BOLD DISPLACEMENT BOLT-LOADED SIN SITU HYDROGEN CRACK GROVE. 6. AUTHOR(5) Gregory N. Vigilante, John H. Underwoods	PECIMEN TO MEASURE WTH IN HIGH STRENGTH ST	EELS	AMCMS No. 6111.01.91A1.100
Gregory IV. Vignance, John H. Onderwi	ood, and Daniel Clayon		
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hydrogen-induced cracking susceptibility the hydrogen crack growth rates and thr 100. Additionally, the severe susceptil reliable, in situ crack measurement methor steel bolt coupled to an automatic data act loaded specimen to relate load to crack g	y of high strength steels. The con- reshold stress intensity of AF141 bility of high strength steels has od, called the instrumented bolt. equisition system. New expression rowth. Our study determined the AF1410, respectively. Thresho	stant displacement bolt-load 0—both conventionally an necessitated the application The instrumented bolt consists have been developed for at Stage II crack growth rately stress intensity levels for	ead to a great deal of investigation on the ded specimen has been used to determine d isothermally heat treated—and AerMet in and modification of a low cost, highly sts of a full bridge, strain-gaged stainless use with the instrumented bolt and boltes for the AF1410 were 1.1E-2 and 2.3E-2 or AF1410 were 16.0 and 13.7 MPa m ^{1/2} , ess intensity was 14.1 MPa m ^{1/2} .
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THE ROLE OF VANADIUM CARBIDE TRAPS IN REDUCING THE HYDROGEN EMBRITTLEMENT SUSCEPTIBILITY OF HIGH STRENGTH ALLOY STEELS			AMCMS No. 6111.01.91A1.100		
6. AUTHOR(S)					
G.L. Spencer and D.J. Duquette (RP.	I, Troy, NY)				
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High strength alloy steels typically used for gun steel were investigated to determine their susceptibility to hydrogen embrittlement. Although AISI grade 4340 was quite susceptible to hydrogen embrittlement, ASTM A723 steel, which has identical mechanical properties but slightly different chemistries, was not susceptible to hydrogen embrittlement when exposed to the same conditions. The degree of embrittlement was determined by conducting notched tensile testing on uncharged and cathodically charged specimens. Chemical composition was modified to isolate the effect of alloying elements on hydrogen embrittlement susceptibility. Two steels—Modified A723 (C increased from 0.32% to 0.40%) and Modified 4340 (V increased from 0 to 0.12%)—were tested. X-ray diffraction identified the presence of vanadium carbide, V ₄ C ₃ , in A723 steels, and subsequent hydrogen extraction studies evaluated the trapping effect of vanadium carbide. Based on these tests, it was determined that adding vanadium carbide to 4340 significantly decreased hydrogen embrittlement susceptibility because vanadium carbide traps ties up diffusible hydrogen. The effectiveness of these traps is examined and discussed in this paper.					
14. SUBJECT TERMS	ida Tana Hadanaa E. 1 tal	of Charl 4240 and 1: 5	15. NUMBER OF PAGES		
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The objective of this work was to documen with XM230 charge. The steady, axisymmooundary values at points on the ballistic.	etric flow was determined by	use of the NPARC Computat	ional Fluid Dynamics Code, given inflow
integration of the distribution over the projects it enters the brake section of the tube.	ected lateral surface of the pro	ojectile gives an estimated side	force of 500,000 pounds on the projectile
contribute to balloting and mechanical wear otating band surfaces. The effect of blow	r of the tube. The same nun	nerical solution computes loc	al heat transfer rates on the obturator and
resent work will provide a basis for further	r understanding the combine	ed effects of abrasive and che	mical erosion. The present computations
ssume that the wear gap between project resented at two points on the ballistics to	raiectory, 2.212 and 5.256 r	o men and that the obturator	protrudes 10% into the gap. Results are
btained for projectiles with and without ob	turator and band. At the 2.2	12 meter location, the latter y	rielded maximum local heat transfer rates
on the barrel surface that exceeded 30 time	es the heat transfer compute	d at 1.7 inches upstream of th	e projectile's base (i.e., in the projectile's
wake boundary layer). With the obturator ransfer computed at 6.7 inches upstream of	and band, and at the same	travel point, the heat transfer	ratio peaked at 2040, with the wake heat
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6. AUTHOR(S)			
S. Sopok, P. Vottis, P. O'Hara, G. Pflegl,	and C. Rickard		•
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Distinct erosion patterns and mechanisms at	re emerging as our gun erosion	databasa ingrassas for in	
tubes with M829A2 rounds. Variability exi	sts for M256 guns with M829	A2 rounds depending on ro	und count, round type, round-conditioning

temperature, and their order. Our M256/M829A2 gun system erosion model—with its interior ballistics, thermochemistry, and boundary layer components—is constantly being guided and refined by the erosion and materials analysis data from fired gun tubes. A recent refinement includes improvement of the gun steel subsurface exposure model due to high quality, difficult to obtain data from in-service M256 tubes. Other recent refinements to the boundary layer heat transfer model are based on thermal data from M256 tubes. These refinements include the improvement/incorporation of case gas cooling effects, turbulent gas mixing/heating effects, and a very minor contribution from forcing coneinduced vena contracta cooling effects. These latter refinements are calibrated away from crack walls by positional thermal wall repacking depth, thermal wall transformation depth, and thermocouple data. A comprehensive gun erosion model and multiple single-shot erosion condemnation predictions are described for the 120-mm M256 gun with its M829A2 round for hot-conditioned rounds only, ambientconditioned rounds only, cold-conditioned rounds only, and an equal distribution of hot/ambient/cold-conditioned rounds. The gun erosion mechanism consists of heat checking the inert chromium plate, subsequent interfacial degradation of the subsurface gun steel substrate at the chromium crack bases, then chromium platelet spalling, and subsequent bare gun steel gas wash. This gun erosion model correctly calculates and predicts that the worst eroded region is at 1.2 to 2.4 meters from the rear face of the tube. The excessive muzzle wear is by a different, purely mechanical gas wash-free mechanism. Most importantly, given herein are the relative erosion-related effective full-charge values of the fielded M256 gun kinetic energy rounds at various round-conditioning temperatures.

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6. AUTHOR(S) S. Sopok, P. Vottis, P. O'Hara, G. Pfleg	gl, and C. Rickard		
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patterns and mechanisms are emerging, round-conditioning temperature, and the and boundary layer components—is conrecent refinement includes the improven service M256 tubes. Other recent refine refinements include the improvement/incontribution from forcing cone-induced positional thermal wall repacking depth, described for the 120-mm M256 gun will described for retired 120-mm M256 gun will make and M829A2, and their three roundscheding the inert chromium plate, subsequeroded region is at 1.2 to 2.4 meters from	Variability exists for M256 guns ir order. Our M256/M829Ax gunstantly being guided and refinedment of the gun steel subsurface ments to the boundary layer hear accorporation of case gas cooling vena contracta cooling effects, thermal wall transformation depith its M829Ax series rounds, tube serial #1988. For this gund-conditioning temperatures, hequent interfacial degradation of ent bare gun steel gas wash. The the rear face of the tube. The exercian are the relative erosion-related	s with M829Ax series round in system erosion model—will by the erosion and material exposure model due to high at transfer model are based on effects, turbulent gas multiple of the series of the series and thermocouple data. In addition, a detailed should tube, the erosion prediction tot, ambient, and cold. The the subsurface gun steel sultiple gun erosion model correctessive muzzle wear is by a content of the subsurface gun steel sultiple gun erosion model correctessive muzzle wear is by a content of the subsurface gun steel sultiple gun erosion model correctes gun erosion model corrected gun erosion erosi	M829Ax series rounds, distinct erosion is depending on round count, round type, the its interior ballistics, thermochemistry, is analysis data from fired gun tubes. A quality, difficult to obtain data from internal data from M256 tubes. These ixing/heating effects, and a very minor ure calibrated away from crack walls by A comprehensive gun erosion model is includes the two types of rounds fired, gun erosion mechanism consists of heat obstrate at the chromium crack bases, then the calculates and predicts that the worst different, purely mechanical gas wash-free is of the fielded M256 gun kinetic energy
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still important to determine the erosion is rely on the M829 round for baseline dis M829A2 rounds, thus necessitating the depending on round count, round type, round epending on the depending on the series of the depending on the series of the series	spersion testing of that gun. Today the consideration of M829 round effects for cound-conditioning temperature, and the service and out-of-service 120-mm has ochemistry, and boundary layer component refinement includes improvement. Other recent refinements to the bound include improvement of case gas cooling effects. These latter refinention depth, and thermocouple data. For the 120-mm M256 gun with its M82 usual distribution of hot/ambient/cold-correfacial degradation of the subsurface generated gas wash. This gun erosion mode. The excessive muzzle wear is by a consideration of the cases in the subsurface generated and cases of the subsurface generated gas wash. This gun erosion mode.	is that have fired the most recent keing generally results in M256 guns any erosion analysis. Variability eir order. Distinctive erosion patter M256 tubes with M829 rounds. In the ments—is constantly being guided of the gun steel subsurface exposs lary layer heat transfer model are laffects, turbulent gas mixing/heatiements are calibrated away from A comprehensive gun erosion and or ound for hot-conditioned round inditioned rounds. The gun erosion un steel substrate at the chromium del correctly calculates and predict different, purely mechanical gas were applied to the control of the	ng effects, and a very minor contribution is crack walls by positional thermal wall model and multiple single-shot erosion is only, ambient-conditioned rounds only, a mechanism consists of heat checking of a crack bases, then subsequent chromium is that the worst eroded region is at 1.2 to wash-free mechanism. Most importantly, gy rounds at various round-conditioning
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